Reliability of rice husk ash as substitution of portland composite cement producing green concrete

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ABSTRACT

Production of cement contributes significantly to air pollution. Previous research has shown that rice husk ash can partially replace ordinary Portland cement in the concrete mixture. This ordinary cement in Indonesia has rarely been used and replaced with Portland composite cement. Based on this phenomenon, it is necessary to know whether rice husk ash is also appropriate as a substitute for Portland composite cement. This study investigates the properties of rice husk ash by using x-ray fluorescence spectrometer and scanning electron microscope. Furthermore, the properties of cement paste were obtained by Vicat testing at replacement levels of 0, 2.5, 5, 7.5 and 10 %, respectively by weight of cement. This research was conducted in the laboratory experiments. Different from other reports, curing of specimens were not performed for up to 28 days. Treatment was performed only at room temperature without immersion, as occurs in foundation work. The result of this research showed that the higher the RHA content was in the cement paste, the higher the percentage of normal consistency. Although the setting time of cement pastes using rice husk ash was longer, it was still suitable for the requirements outlined in Indonesian standard regulations. This study provides an opportunity to use the abundant ash of rice husk ash as a substitute for composite cement in creating environmentally friendly concrete known as green concrete.

Key words : *Rice husk ash, Portland composite cement, Green concrete, Setting time*

Introduction

The Government of Indonesia states that industrial enterprizes and industrial estate companies must utilize natural resources in an environmentally friendly and sustainable manner. It further states that sustainable and environmentally friendly use of natural resources is done by reduction and reuse waste.

Cement industry as a provider of construction material using non-renewable natural resources in large numbers. Furthermore, at another point of view, this industry is not in line with government regulations mentioned above. Besides, it is not environmentally friendly because it causes air pollution.

This phenomenon has produced a new type of concrete known as green concrete. The nature of the green concrete is to meet several criteria, namely the concrete with a minimum clinker content, with inorganic and organic waste products. For example, the application of coal waste as fly ash for mixture cement to make green concrete. Using the coal waste represent one of the programs of environment conservation which is in the form of reuse, recycle and reduce. Therefore, this research can be used a lead project in development and substance invention of environmentally friendly anti moss (Setyono, 2012). One of the many green binders studied at an agricul-

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tural country is rice husk ash (RHA).

Several previous studies about the properties of RHA have been done. The results of X-ray characterization of RHA showed an amorphous phase. The physical characteristic of RHA regarding fineness and chemical composition plays a vital role in determining the strength development. RHA has been provided to be of very high silicon dioxide content and is a very reactive pozzolan, reasonable as supplementary cementing material (Ahmad *et al.*, 2013; Begum *et al.*, 2014; Ogork *et al.*, 2015)

Reference (Noushad, Ab Rahman, Husein, Mohamad and Ismail, 2012) illustrates the synthesis of nano silica from rice husk. The synthesis was done by precipitation using different acids, namely, orthophosphoric acid and nitric acid which yielded nano silica. The size of silica was around from 70nm to 400nm when either acid was a convenience in conjunction with polar solvents. The silica particles were irregular in shape when nonpolar solvents were used. Besides, the particle size of silica was not estimated.

Although RHA possesses lower SiO_2 content and larger particle size compared to silica fume, the finely-ground RHA becomes a higher surface area due to the nanoscale pores on every single RHA particle. These nanoscale pores with size less than 50 nm largely commit to the high surface area and high pozzolanic reactivity of RHA (Xu *et al.*, 2016). This finely-ground RHA named nano and micro RHA on mortars were investigated by (Balapour *et al.*, 2017). It was found that the utilization of nano and micro RHA increased mortar performance in the long term, whereas the nano RHA showed to noticeable improvements at both early and long-term ages. Results confirmed that the strength and durability properties of mortars consist of nano RHA up to 7.5% levels of replacement by weight of cement gradually increased in comparison with control mix. However, mortars incorporating 2.5% nano RHA together with 12.5% micro RHA established the best improvements for durability and strength development at the age of 90 days.

It is recommended that the RHA should be burned at 600° C for 60 min and then ground for 30 min in a ball mill, while steel slag should be ground in a ball mill for 60 min. The essential physical and mineralogical characteristics of RHA are the amount of amorphous silica, surface area, smoothness, and the amount of carbon, depending on the temperature, environment and long burning. While the properties of the ash as pozzolan was determined from the amount of amorphous silica (Chen *et al.*, 2014) and (Ganapat, 2012). A concrete mixture containing up to 25% RHA as a replacement of ordinary Portland cement (OPC) produced the same strength as the concrete containing 100% OPC. Higher proportions (40%) of RHA could be used for non-structural works where strength is not critical (Khan *et al.*, 2012) and (Chao-Lung *et al.*, 2011)

In South Sulawesi, there were an estimated 908 million tons of rice husk ash originating from the 4.54 million tons of rice production. Furthermore, if the burning of rice husk yield ash for about 15%, it will produce RHA of 136,200 ton (Ahmad *et al.*, 2013).

The reality in Indonesia, It is rarely found the type of OPC. Type of cement on the market right now is composite cement known as the Portland composite cement (PCC). This fact can lead to problems if the RHA can also be used to replace PCC partially. Furthermore, compounds contained in the two types of cement is different. Therefore, the objective of this research is to find the behavior of mixed binder (RHA and PCC) to produce green concrete. Indicators in this study for the reliability of RHA as a substitute for cement PCC are characteristic of RHA and setting time binder paste. Also, utilization RHA will reduce the production of Portland cement as well as reduce the waste disposal volume to build a better environment.

Materials and Methods

A. Materials

This research used the Portland composite cement (PCC) as the major binder material. The RHA sourced from brick manufacturing that uses rice husk as fuel (Figure 1) and then ground by a Los Angeles abrasion machine. The RHA utilized in this research was that passed sieve No. 200.

B. Method

Chemical compositions of RHA and Portland composite cement (PCC) were analyzed by x-ray fluorescence spectrometer (Figure 2). Physical and particle shape of the materials by scanning electron microscope (SEM) were also investigated (Figure 3).

Normal consistency (water demand) of mixed binder (RHA-PCC) and PCC paste was determined according to ASTM (1997b). In this code, pastes

Fig. 1. Rice Husk Ash

Fig. 2. Rigaku Miniflex II XRD

Fig. 3. Vega3tescan SEM-EDX

were arranged, and the amount of water marked to penetrate the Vicat testing needle (10 mm diameter) by 10 mm.

The setting time test followed the ASTM (1997a). The Vicat apparatus (Figure 4) was also used to determine the setting time of the mixed binder as well as the PCC paste. The standard paste measured for

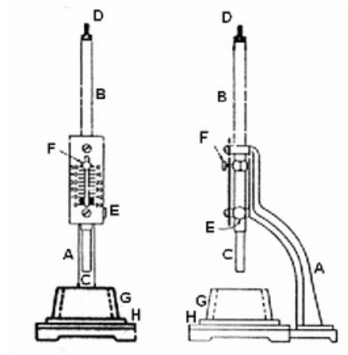

Fig. 4. Vicat Apparatus

the initial setting time to penetrate the Vicat testing needle (1 mm diameter) by 25 mm. The normal consistency test conducted to measure the required water. The final setting time was the measured time when there was no penetration of the needle observed by the same testing method. The ratios of RHA: PCC were varied as 2.5:97.5, 5:95, 7.5:92.5, and 10:90 by weight (Table 1).

Table 1. Material Used for Preparation of Paste Cement

No.	Percentage of PCC (%)	Presentage od RHA (%)
1	100	0
2	97.5	2.5
3	95	5
4	92.5	7.5
5	90	10

Results

A. Chemical Compositions

The result of the RHA characterization by XRD is shown in Figure 5. The graphic form is not smooth by showing there are several peaks. These peaks indicate that there has been a phase of crystalline silica oxide into the cristobalite or tridymite phases. The RHA category, therefore, is largely amorphous and partially crystalline. This phase also occurs in research conducted by Deshmukh *et al.* , (2012). The amorphous phase is formed by burning rice husks above 400 ºC. The cristobalite and tridymite phases occur in combustion above 400 ° C.

The result of RHA characterization that passed sieve No.200 is shown in Figure 6. The graphic form shows a smoother graph, without any peak of the cristobalite or tridymite phases. Based on this result,

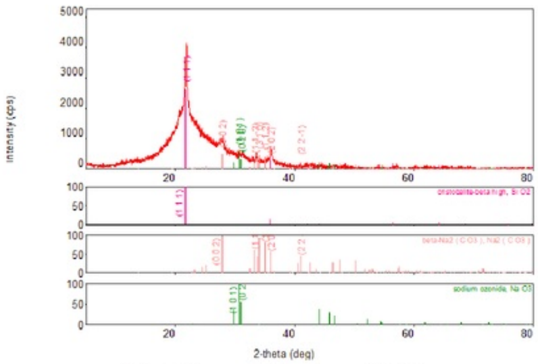

Fig. 5. X-ray diffraction of RHA

to guarantee the RHA at the amorphous phase, the RHA previously passes filter No.200. Table 2 and 3 show the oxide composition of PCC and RHA respectively. It should be noted that CaO of PCC was 60.33% while SiO_2 of RHA was 95.23%.

B. Physical and particles shapes of RHA and PCC

Figure 7 and 8 show the particle shapes of PCC and RHA using SEM-EDX. SEM image of RHA shows very porous and spongy structures, which are angular, spongy, irregularly shaped particles with a porous cellular surface.

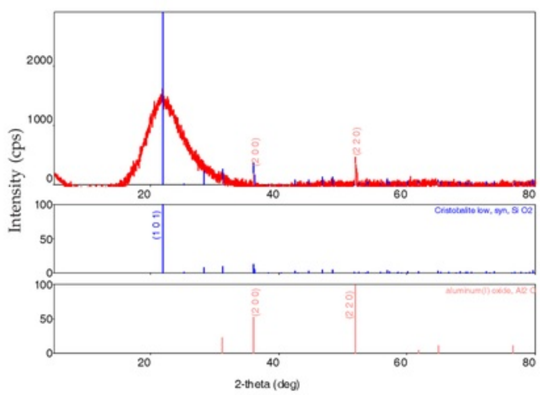

Fig. 6. X-ray diffraction of RHA (passed sieve No. 200)

Table 2. Chemical Composition of PCC

Chemical composition	Content (%)
SiO_2	95.23
Al_2O_3	1.24
K_2O	1.80
Na_2O	0.21
MgO	0.52
P_2O_5	1.00

Table 3. Chemical Composition of RHA

Chemicalcomposition	Content(%)
CaO	60.33
SiO_2	21.50
Al_2O_3	8.60
FeO	3.17
SO_3	2.69
K_2O	1.80
Na_2O	0.99
MgO	0.58

RHA had morphology form of amorphous grains with grain sizes varying up to 50 µm. SiO_2 as the main component is visible (shiny white surface). Moreover, the figures represent that the shape of the particles of RHA is irregular..

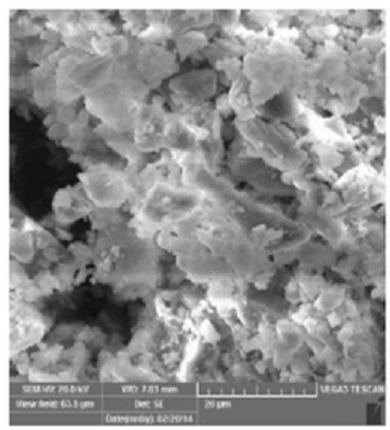

Fig. 7. SEM of PCC

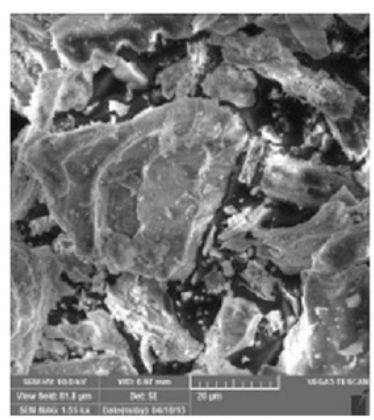

Fig. 8. SEM of RHA

C. Normal Concistency

Fig. 9 shows the Vicat testing to determine the normal consistency test of paste cement. This normal consistency test was performed to find the percentage of water required for setting time. This percentage was obtained by trial and error so that the penetration needle reaches 10 ± 1 mm. Figure 10 shows the trend of the relationship between the percentage of RHA and normal consistency. The higher the RHA content is in the paste, the higher the percentage of normal consistency. It means that the higher the content of RHA, the higher the water is required in the paste mixture. Therefore the water requirement needs to be considered in making RHA contained concrete. Due to the use of large amounts of water can decrease the compressive strength of the concrete itself.

The normal consistency of PCC paste was 24% while those of RHA-PCC pastes were 30.568% to 32.165%, depending on RHA content. Paste with 2.5% of RHA had the normal consistency of 30.567% and increased slightly to 32.165% in a paste with 10% of RHA. The normal consistency of RHA-PCC pastes needed more water than that of cement paste because of the high porosity of the RHA. RHA which had porous, spongy particles, more specific surface areas of the pozzolans, was observed in SEM analysis as reported by (Karim *et al.*, 2015)

Fig. 9. Vicat Testing (Normal Consistency)

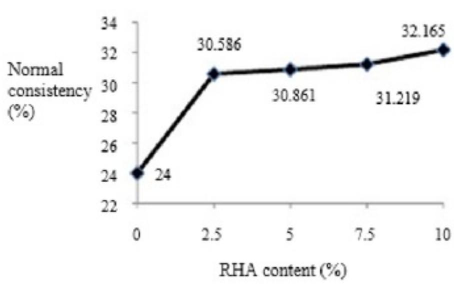

Fig. 10. Normal consistency

D. Setting Time

Figure 11 shows the vicat testing to determine the setting time of paste cement. Initial setting times of PCC and mixed binder are presented in Table 5. The use of rice husk ash in cement paste influenced the length of initial setting time. The initial setting time of PCC paste was 119.1 minute, while that of 2.5% RHA increased moderately to 135.8 minutes. Furthermore, the initial time of 5%, 7.5% and 10% RHA increased slightly to 135.79, 137.3, and 146.3 minutes, respectively. The initial setting times of cement paste was within the allowance specified by ASTM C 150 which should not be less than 45 min.

Figure 12 illustrates the comparison between initial setting time of PCC-RHA paste and cement PCC paste. Table 4 indicates that the initial time of mixed binder paste was higher than that of paste using 0% RHA. While that of the blended cement paste was about 1.140 to 1.228 times greater than that of the PCC paste.

Fig. 11. Vicat Testing (Setting Time)

Table 5 shows the final setting times of PCC and mixed binder. The use of rice husk ash in cement paste also influenced the length of final setting time. The final setting time of PCC paste was 165 minute,

Table 4. Initial Setting Time

No.	Content of RHA(%)	Initial setting time (minute)
1	0	119.1
2	2,5	135.8
3	5	135.79
4	7,5	137.3
5	10	146.3

while that of 2.5% RHA increased slightly to 180 minutes. The final time of 5% RHA and 7% RHA were equal to that of 2.5% RHA. Furthermore, the final time of 10% RHA increased slightly to 195 minutes. The final setting times of cement paste was within the allowance specified by ASTM C 150 which should not be greater than 375 min.

Discussion

According to the chemical composition, as specified by ASTM, RHA could be classified as pozzolan since the amount of Al_2O_3, Fe_2O_3, and SiO_2 was

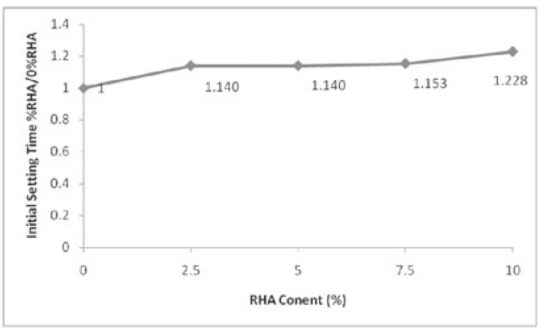

Fig. 12. Comparison inital setting time

Table 5. Final Setting Time

No.	Content of RHA (%)	Final setting time (minute)
1	0	165
2	2,5	180
3	5	180
4	7,5	180
5	10	195

96.47%, Loss of Ignition (LOI) was 4.68%, and moisture content was 1.15% (Table 6). According to ASTM C (1997d), LOI of natural pozzolanic material shall not be higher than 10.0%. Thus RHA in this experiment meets the requirement.

Table 6. Chemical Composition of RHA

Criteria	Result	Standard
SiO2+Al2O3+Fe2O3	96,47%	> 70 %
LoI	4,68 %	< 10%
Water Content	1,15 %	< 3%

Similarly from previous research, all particles of the shape of the PCC and RHA material were irregular. PCC had a solid particle with some rough surface while RHA had a rough surface with high porosity. With high porosity and uneven shape, the RHA mixture absorbed water into their particulate matter and resulted in the high normal consistency of the PCC-RHA paste

Figure 13 provides the comparison between normal consistency of mixed cement paste RHA and cement paste 0% RHA. The consistency of mixed binder paste was higher than that of paste using 0% RHA. Meanwhile, the consistency of the blended cement paste was about 1.274 to 1.340 times greater than that of the PCC paste.

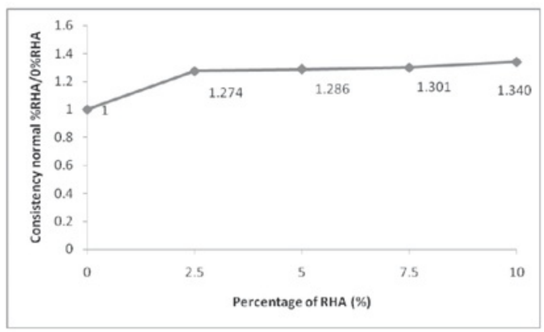

Fig. 13. Comparison consistency normal paste cement

Figure 14 describes the comparison between final setting time of PCC-RHA paste and cement PCC paste. The final time of mixed binder paste was slightly higher than that of paste using 0% RHA. The final time of the blended cement paste was approximately 1.091 to 1.182 times greater than that of the PCC paste.

In RHA-PCC paste, the $Ca(OH)_2$ from PPC reacted with SiO_2 from RHA to form CSH while Portland cement reacted with water and formed CSH directly. The long setting times of RHA-PCC paste is because the pozzolanic reaction between pozzolan and lime is usually much slower than the hydration of cement. The increase in final setting time was due

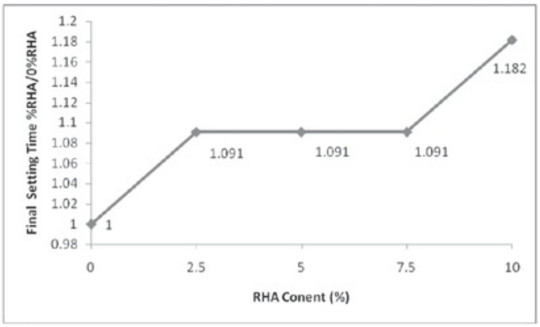

Fig. 14. Comparison consistency normal paste cement

to dilution of cement in the mix which leads to slower hydration reaction when compared to that of cement. Furthermore, the setting time of the paste was longer because of the spongy particle size of RHA. These particle absorb more amount of water which can be seen from the normal consistency data. Therefore, the delay of the hydration process occurs in paste used RHA.

A similar finding was also reported by (Begum *et al.*, 2014). The initial and final setting times were longer with an increase in RHA content. When RHA replaces cement, the rate of reaction with water and the quantity of heat released also declines. Therefore it is leading to slow stiffening of the paste. As the hydration process requires water, So, more water was also needed for the purpose to continue. Meanwhile, the reaction between cement and water is exothermic, leading to liberation of heat and evaporation of moisture and consequently stiffing of the paste.

Conclusion

The results of this study concluded that the RHA can be used to partially replace the Portland Composite Cement. It can be seen from :

1. The chemical composition of PCC showed that the compound of CaO reaches 60.23%, whereas that of SiO_2 reaches 21.45%. The RHA is in the amorphous phase and compounds containing high SiO_2 (95.23%) that can be categorized as a pozzolan material and can be used as a cement substitute material.
2. The higher the RHA content is in the paste, the higher the percentage of normal consistency. Paste without and with 10% of RHA had the normal consistency of 247% and 32.165%, respectively.
3. The higher the RHA content is in the paste, the longer the initial and final setting time. Paste without RHA had initial and final setting times on 119.1 and 165 min. Meanwhile, paste with 10% of RHA had initial and final setting times on 146.3 and 195 min.

Acknowledgement

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